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Static Mechanical Properties of GFRP Laminates with Waste GFRP Interleaf

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Abstract

A recycle method of GFRP is investigated in this study. Waste GFRP was divided into short glass fibers and resin fragments by milling. However the tensile strength of composites with the chips of waste GFRP is low, the composites are expected that fiber bridging and higher compressive strength than resin. These advantages could be shown by suitable application. We examined the aptitude of the chips of waste GFRP for interleaf materials of unidirectional composite laminates. The tensile strength of interleaved composite laminates was improved and found to be better than that predicted using the law of mixture in all fiber directions. Shear support and fiber bridging by the interleaf seemed to improve the tensile strength of composite laminates.

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Keywords: Waste GFRP; Interleaf; Composite laminates; Law of mixture;

1. Introduction

Fiber reinforced plastics (FRP) have been used in various structures because the specific stiffness and strength of FRP are higher than those of other materials. However, the amount of FRP usage has also increased. The amount of waste GFRP is 400,000 tons in recent years in Japan. Most of them are disposed in landfills and by incineration. Only small amount of the waste has been used as fuel for concrete production.

Material recycling is a better method for waste FRP; thus we studied their reuse. Other researchers have developed methods of separating fibers and resin [1]. The fibers after being separated can be used as reinforcement for new FRP.

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In this study, we tested a simple and rough method of reuse. An additional process for reuse is the milling of waste GFRP. By milling, chips that are mostly short glass fibers are derived from waste GFRP. The chips are inadequate as reinforcement for improving tensile strength of resin, but they have a high compressive strength compared with tensile strength. This means that they also have high shear strength.

We fabricated composite laminates with interleaves of waste GFRP chips to take advantage of their high compressive and shear strengths. These composite laminates are so-called hybrid composite laminates [2]. Static tests on the laminates were carried out and we considered the mechanism of the effect of the interleaves.

2. Production of composite laminates

2.1. Chips of waste GFRP

Waste bathtubs made of GFRP were used for material recycling. First, the bathtubs were milled by a rolling mill of Rasa Industries. Next, we used an atomizer of Tokyo Atomizer. The chips obtained by milling from waste GFRP were applied to interleaves. Figure 1 shows the photographs of the chips. The chips appear to be fragments of fibers with resin as shown in Figure 1(a). We found that the chips are mostly fibers from the microscopy photograph in Figure 1(b). Then, the chips were placed in water and mixed thoroughly. After that, the chips were spread uniformly on a polymer net. Finally, the chip layers were dried in an oven.

2.2. Molding of laminates

Composite laminates were made by vacuum-assisted resin transfer molding (VaRTM). The fabrics used were unidirectional glass fibers by SARTEX, which consist of 0° at 94.6%, 90° at 4.4% and stitch at 1.0%. This layer is called unidirectional (UD) layer; however, the layer includes 90° fibers in this study. Spa MV-5000 vinyl ester resin by Ishikawa Ink was used as matrix.

3. Experimental procedure

3.1. Specimens

We molded [0_3], [45_3] and [90_3] as normal composite laminates. [0/c/0/c/0], [45/c/45/c/45] and [90/c/90/c/90] were molded as composite laminates with interleaves of waste GFRP chips. We call these

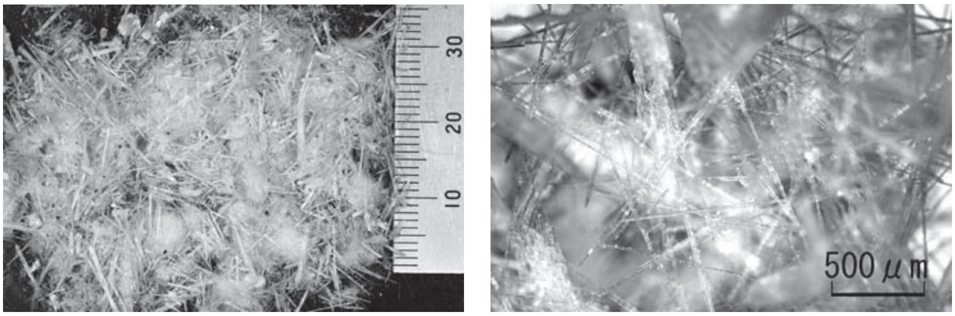


Fig. 1. (a) chips of waste FRP; (b) microscopy photograph of waste FRP chips

hybrid laminates. Here, “c” means the chip interleaf. Configurations of tensile and compressive specimens are shown in Figs. 2 and 3.

3.2. Tensile and compressive tests

The testing machine used was Shimadzu AG-5000A, which has a 50 kN load capacity. The cross-head speed was 1.0 mm/min on both tensile and compressive tests. In the tensile test, the extensometer of 50 mm gage length and the strain gages of 2 mm gage length were used for strain measurement. In the compressive test, strain gages of 2 mm gage length were used. Compressive tests were carried out for the resin and the resin with chips of waste GFRP. To avoid out-of-plane buckling failures, a support jig of ASTM D 695-90 type was used for the compressive tests.

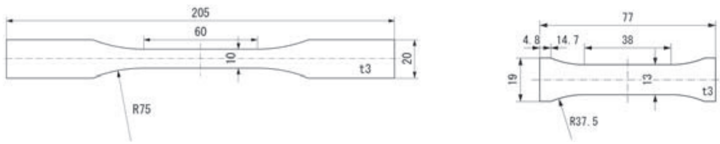


Fig. 2. Specimen configuration (a) for resin tensile test; (b) for resin and resin with chips compressive tests; [mm]

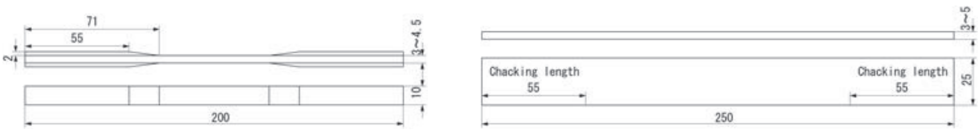


Fig. 3. Specimen configuration (c) for 0° tensile test; (d) for resin with chips, 45° and 90° tensile tests; [mm]

4. Results and discussion

4.1. Resin and resin with chips of waste GFRP

Figure 4 and Table 1 show stress-strain (S-S) curves and static properties, respectively. Compressive fractures did not occur within an applicable range of the ASTM D 695-90 jig. However, we found out that the ultimate strength and the fracture strain of the compressive test are higher than those of the tensile test.

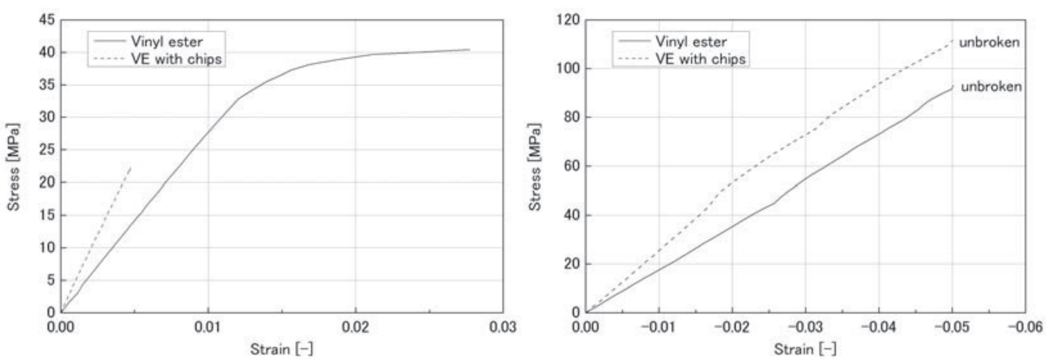


Fig. 4. Stress-Strain curves of resin and resin with chips (a) tensile tests; (b) compressive tests;

The chips seemed to degrade the tensile strength but not the compressive one.

It is well known that the stress field of the compressive test is compressive at any angle with stress transformation. Thus, the prime factor for the final fracture seems to be shear stress. The resin with the waste GFRP chips appears to have a high shear strength compared with the tensile strength.

Table 1. Results of resin and resin with waste GFRP chips

Material	Vinyl ester	Vinyl ester with chips
Tensile strength (MPa)	40.4	23.0
Fracture strain (%)	2.81	0.48
Young's modulus (GPa)	2.85	4.85

4.2. 0° laminates

Figure 5(a) and Table 2 show S-S curves and static properties of 0° laminates, respectively. The tensile strength of the normal laminates was higher than that of the hybrid laminates because the tensile strength of the interleaf is very low as described in the previous subsection. However, the experimental tensile strength of the hybrid laminates was higher than that predicted using the law of mixture.

Figure 5(b) shows the side of a 0° laminate after fracture. UD layers fractured into short fiber fragments. The interleaves hold their layer shape after the fracture; however, multiple cracks were found in them. Thus, the interlaminar shear stress seemed to support UD layers.

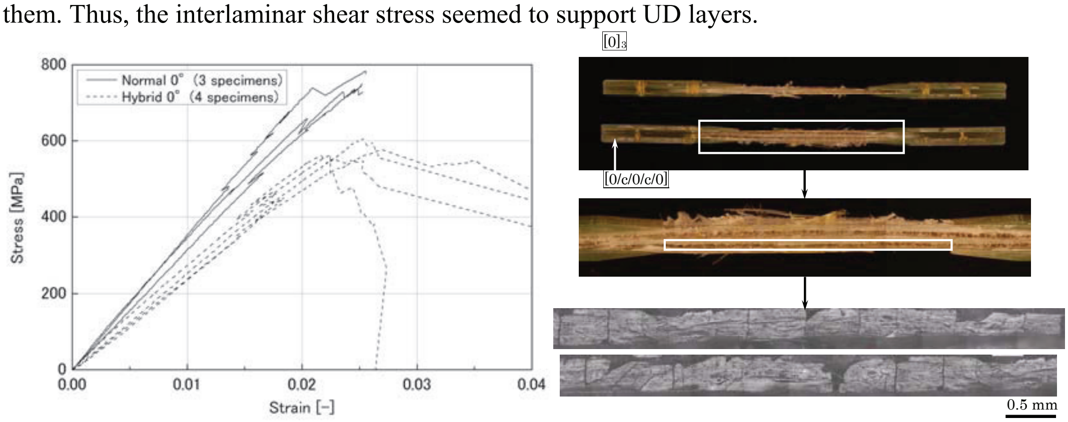
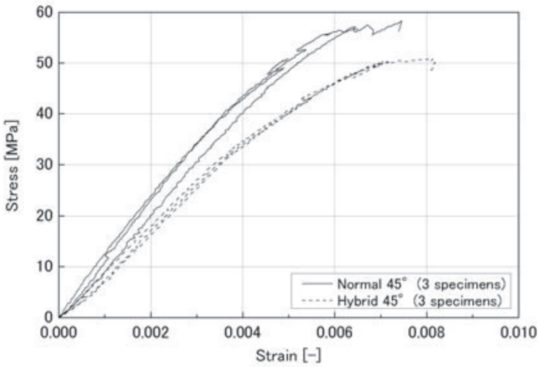


Fig. 5. (a) Stress-Strain curves; (b) side section after fracture of 0° laminates

Table 2. Results of $[0_3]$ and [0/c0/c/0]

Material	$[0_3]$	[0/c/0/c/0]	Law of mixture
Tensile strength (MPa)	736	605	475
Fracture strain (%)	2.44	2.66	-
Young's modulus (GPa)	31.4	24.3	21.7



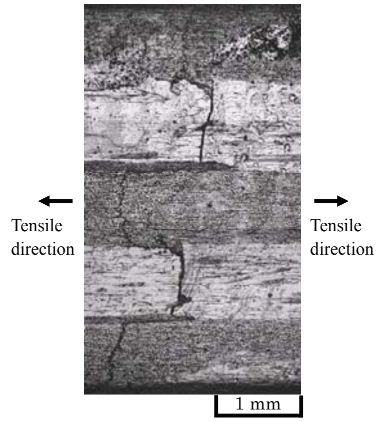


Fig. 6. (a) Stress-Strain curves; (b) side section after fracture of 45° laminates

Table 3. Results of [45_3] and [45/c/45/c/45]

Material	[45_3]	[45/c/45/c/45]	Law of mixture
Tensile strength (MPa)	56.7	50.8	44.5
Fracture strain (%)	0.65	0.81	-
Young's modulus (GPa)	11.2	9.11	8.88

4.3. 45° laminates

Figure 7 and Table 3 show S-S curve and static properties of 45° laminates, respectively. The tensile strength of the hybrid laminates was slightly lower than that of the normal laminates because the tensile strength of the 45° normal laminates is closer to that of the interleaf. The fracture strain of the hybrid laminates is higher than that of the normal laminates. The same shear support as 0° to occur. Figure 6(b) shows the side of a 45° laminate after fracture. The fiber bridging effect is found in this figure.

4.4. 90° laminates

Figure 7(a) and Table 4 show S-S curves and static properties of 90° laminates, respectively. The tensile strength of the 90° normal laminates was still higher than that of the interleaf. However, the tensile strength of the hybrid laminates was the same as that of the normal laminates. The law of mixture cannot predict this result. Moreover, the fracture strain of the hybrid laminates was improved by about 60%. After the fracture, multiple cracks were found in the UD layer and interleaves of the hybrid laminates as shown in Figure 7(b). Thus, shear support and fiber bridging improve the strength and these effects seem to become the maximum in the 90° layer.

5. Conclusions

- The tensile strength of hybrid laminates was improved and found to be better than that predicted using the law of mixture in all fiber directions.
- From the observation of fractured specimens, shear support and fiber bridging by the interleaf, which was made of waste GFRP chips, seemed to improve the tensile strength of hybrid laminates.
- The compressive strength of the resin with the waste GFRP chips was higher than its tensile strength. This seems to affect the tensile strength of the hybrid laminates.

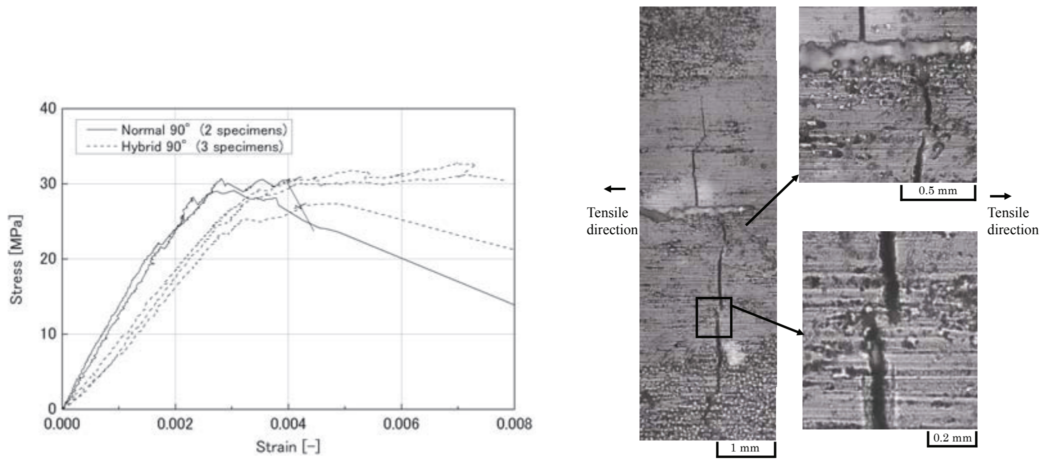


Fig. 7. (a) Stress-Strain curves; (b) side section after fracture of 90° laminates

Table 4. Results of [90_3] and [90/c/90/c/90]

Material	[90_3]	[90/c/90/c/90]	Law of mixture
Tensile strength (MPa)	29.1	31.2	26.9
Fracture strain (%)	0.49	0.78	-
Young’s modulus (GPa)	14.6	8.37	11.0

Acknowledgements

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